Improving PM_{10} Fugitive Dust Emission Inventories

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ABSTRACT

PM_{10} emissions inventories are required for PM_{10} attainment demonstrations for State Implementation Plans (SIPs). California contains four federal PM_{10} serious non-attainment areas and six moderate federal PM_{10} non-attainment areas, which combined, include over one-third of the state's area. An accurate particulate matter emissions inventory is needed to effectively assess and prioritize sources of PM_{10}, and to develop reasonable, cost effective control strategies. Over the past two years, staff of the California Air Resources Board (ARB) have developed substantially improved methodologies for estimating emissions from the major sources of geologic PM_{10} in the State. We have improved the estimation methodologies for the following source categories: paved and unpaved road dust, windblown dust from agricultural lands, agricultural tilling and harvest emissions, and construction operation emissions. The inventory improvements resulted in a downward adjustment of the statewide PM_{10} emission estimates of over 50% and enhanced our understanding of the spatial and temporal distribution of PM_{10} emissions. The improvements also provide estimates which more closely track the seasonal particulate matter trends observed with ambient PM_{10} measurements. During the process of improving the inventory we repeatedly discovered the value of working with affected industry and agencies. Their help allowed us to produce better estimates, and their ongoing involvement made it possible to have the inventory results accepted with little contention as the PM_{10} SIPs were prepared and submitted to EPA.

INTRODUCTION

Over one-third of California is classified as federal non-attainment areas for PM_{10} and is required to meet federal PM_{10} control and attainment requirements. The Air Resources Board (ARB) of California's Environmental Protection Agency (Cal/EPA) has maintained a particulate matter (PM) emission inventory for over twenty years. The ARB's emissions database includes PM emissions for hundreds of point, mobile, and areawide sources. Areawide sources comprise about 85% of the total inventoried PM emissions. Until this project, the emissions estimates for areawide PM emissions, such as paved road dust or agricultural land preparation, did not receive much scrutiny outside of the ARB. The requirements to prepare PM_{10} SIPs and their associated attainment demonstrations and control strategies heightened the need for improved PM_{10} emission estimates, and better spatial and temporal allocation of the emissions.

Some of the key elements that went into improving the emission inventory estimates are:

- ▸ Use of updated emission factors;
- ▸ Use of California specific data as input to the emission factor equations;
- ▸ Collection of updated activity data, such as crop acreage, or vehicle miles traveled;
- ▸ Better estimates of when PM_{10} generating activities occur during the year;
- ▸ Use of geographic information systems (GIS) to calculate and spatially allocate emissions;
- ▸ Forming partnerships with those affected by the emission estimates such as industry, air districts, and other agencies.

The remainder of this paper describes the process we used to improve the inventory estimates, and the specific changes made to each category.

I. PM_{10} INVENTORY IMPROVEMENT PROCESS

Move Towards a "Bottom Up" Approach

Areawide emission sources are the largest contributors to directly emitted PM_{10}. These sources include paved and unpaved road dust, windblown dust, agricultural and construction dust, and other sources. Areawide inventories have traditionally been estimated using what can be called a "top-down" approach. This approach multiplies an emission factor, which is determined for a specific unit of activity, by an activity level. The activity level usually represents annual activity for a state or county. This approach is less accurate than using more localized information, and it provides little or no information on the spatial and temporal distribution of emissions.

To achieve our goal of increasing the accuracy of the inventory we needed to collect more detailed input data and develop improved estimation methods. This was done by developing a "bottom-up" approach for estimating PM_{10} emissions wherever possible. With this approach, the intent is to create emission estimates that are more reflective of regional and seasonal variations in actual PM generating activities and conditions, rather than just applying generic factors throughout an entire region.   By using this more detailed, "bottom-up", approach, not only are the PM_{10} inventory estimates more refined and defensible, but the inventory data are also more useful in helping to develop reasonable and cost effective PM_{10} control strategies.

PM_{10} Data Collection Outreach

From the start, it was clear that developing a bottom up approach to estimating PM_{10} emissions from area sources required collecting large amounts of new information about PM_{10} emissions. We recognized that to do this, we needed to actively pursue PM_{10} emissions information from many sources. It was clear that the coordination and assistance of many groups would be needed to develop an improved PM_{10} inventory for an area as large and diverse as California. Figure 1 shows a schematic of the entities targeted as part of the ARB staff's PM_{10} information outreach process. This process included many meetings with industry, researchers, air district staff, and other agencies. The purpose of these meetings was to discuss the current methodologies, and to seek outside help in improving the PM_{10} inventory. The organizations and a description of the information they provided are listed in Table 1.

Our most significant outreach effort was our work with agricultural groups. By working directly with agricultural representatives and the growers themselves, we were able to get more accurate and detailed information about PM_{10} producing activities and develop a consensus on the emission

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estimates prior to their use in any plans or regulations. In particular, we would like to thank the San Joaquin Valley Agricultural Commissioners, the commodity producers, the California Cotton Ginners and Growers Associations, the Nisei Farmers League, and the staff of the San Joaquin Valley Unified Air Pollution control district.

II. UPDATED PM$_{10}$ ESTIMATION METHODOLOGIES

In improving the PM$_{10}$ inventory we focused on the five inventoried particulate matter categories that had the largest overall emissions. These categories are:

- ▸ Paved Road Dust
- ▸ Unpaved Road Dust
- ▸ Construction Operation Dust
- ▸ Agricultural Land Preparation and Harvest Dust
- ▸ Agricultural Windblown Dust

Updates to the PM$_{10}$ inventory included changes to the emission factors, activity data, temporal data, spatial data, and general improvements to the overall methodology. Table 2 summarizes the specific types of changes made to each source category. The table also provides a listing of the estimated PM$_{10}$ emissions before and after the inventory updates. The remainder of this section describes the specific improvements made to each source category. For a complete description of the methodologies listed, refer to ARB's document, *"Methods for Assessing Area Source Emissions in California"*[1]. This document is the result of years of work compiling data on emission factors, activity data, and estimation methods.

A. Paved Road Dust

The paved road dust category includes emissions of fugitive dust particulate matter entrained by vehicular travel on paved roads. In California, road dust emissions are estimated for four classes of roads which are: freeways, major streets/highways, collector streets, and local streets. We improved the emission estimates by incorporating changes in five areas. They are:

- ▸ Incorporation of the new EPA paved road emission factor from the Fifth Edition of EPA's AP-42 document (January 1995, Section 13.2.1)[2]
- ▸ Incorporation of California specific roadway silt loading values
- ▸ Update of the county specific Vehicle Miles Traveled (VMT) data
- ▸ Update of the county specific fractions of vehicle miles traveled on each of the four major roadway categories (i.e,. freeways, major roads, collectors, and local roads)
- ▸ Emissions growth for future years was changed so that freeways and major roads are grown based on increases in roadway centerline mileage, and local and collector roads are grown based on increases in VMT. Previously, all roads were grown based on VMT.

Incorporation of all of these changes reduced the paved road dust emission estimates by about 70% from the previous published inventory values. The factor which played the largest role in this decrease was the use of California specific roadway silt loading values. We found, based on silt loading measurements performed by Midwest Research Institute[3], that California silt loadings were approximately one tenth of the median values listed in AP-42. One of the primary reasons for this difference is that the data set used in AP-42 includes many silt loading samples from other states (predominantly Montana) which were known to have high loadings due to road sanding and

other soil sources. These conditions are not representative of California so the new silt loading values were used.

Unlike the AP-42 methodology, we did not split paved roadways into high average daily travel (ADT) and low ADT categories. Instead, we retained the previous ARB method of separately computing emissions for freeways, major roads and highways, collector roads, and local roads. The information to perform these splits was derived from data submitted by California to the Federal government as part of the Highway Performance Monitoring System (HPMS)[4]. Splitting the roads this way gave more flexibility in assigning silt loading values that are more roadway and region specific. For example, in the agricultural San Joaquin Valley, a different silt loading value input was used for their rural local roads because of the expectation of additional suspendable material on these types of roads.

An additional improvement to the paved road methodology is in how we now forecast future year emissions. Previously, paved road dust emissions were grown proportionally to roadway vehicle miles traveled (VMT). We now grow the roadways with high traffic volume and limited access (freeways, major roads, and highways) based on the predicted increases in roadway centerline miles, and not VMT. For the roadways with lower traffic volume and potentially greater loading sources (collectors and locals), we still grow emissions by VMT.

The relationships between VMT and dust emissions are complex and not well understood. However it is hypothesized that for highly traveled roads, as VMT increases, the reentrained road dust emissions, on a per car basis, get smaller. Our current approach assumes that for highly traveled roads an equilibrium condition is reached in which all of the available suspended material essentially remains suspended due to the volume of traffic so additional cars do not produce appreciably greater emissions (tail-pipe PM emissions are negligible). We realize that this approach does not fully describe the intricacies of the actual physical situation, but it is an improvement over the previous forecasting methodology.

B. Unpaved Road Dust

The unpaved road dust category includes estimates of the entrained geologic particulate matter emissions that result from vehicular travel over unpaved roads. The emissions are caused by the mechanical disturbance of the roadway and the vehicle generated air turbulence effects. As with the paved road dust, the largest improvements in this category result from using data specific to California. In this case, research groups at UC Davis[5] and Desert Research Institute[6] performed upwind/downwind emissions measurements while vehicular traffic traveled over unpaved roads. The resulting emission factors were averaged to produce a California specific emission factor of 2.27 lbs PM_{10}/VMT, which is slightly lower than the previous emission factors derived using the AP-42 methodology. In addition, using data available from California's Department of Transportation[7], we improved the estimates of unpaved road mileage. For agricultural unpaved roads we used updated crop acreage data to refine the unpaved road mileage estimates.

To better represent the seasonal variations in unpaved road dust emissions, we apportioned the annual emissions by month based on regional rainfall data. In using this approach, our assumption is that during wet months not only will dirt roads produce less dust per vehicle pass, but there are also fewer vehicle passes during the wet months when the roads are muddy. Even with these improvements, the unpaved road dust category still requires further work to improve the

estimates. Using a single emission factor statewide does not adequately represent the diversity of unpaved roads in the State. In addition, our estimates of VMT on unpaved roads are extremely limited. Because of lack of better information, we now assume that each mile of unpaved road receives ten vehicle passes per day. For agricultural unpaved roads we assume 175 VMT/40 acre parcel. Both of these are broad estimates which clearly need refinement.

C.   Construction Dust

Using an improved emission factor, our estimates of construction dust were reduced by approximately 70%. The construction dust source category includes fugitive dust particulate matter emissions caused by construction activities while building residential structures, commercial structures, and roads. The emissions estimated result from site preparation work which may include scraping, grading, loading, digging, compacting, light-duty vehicle travel, and other operations.

The emission factor used for the estimates is based on work performed by MRI under contract to the PM_{10} Best Available Control Measure Working Group (BACM)[3]. For most parts of the state an emission factor of 0.11 tons of PM_{10}/acre-month is used which is based on observations of the types, quantity, and duration of operations at eight construction sites (3 located in Las Vegas, 5 in California). The bulk of the operations observed were site preparation related activities. The observed activity data were then combined with operation specific emission factors provided in AP-42 to produce site emissions estimates. These site estimates were then combined to produce the overall average emission factor shown. The BACM report also includes an emission factor for worse-case emissions, which is 0.42 tons PM_{10}/acre-month of activity. In some areas of the state, where appropriate activity data were available, this factor was used for some of the construction activities.

D.   Agricultural Land Preparation and Harvest Dust

Improvements to the agricultural land preparation emission category provided some of our most rewarding and worthwhile experiences. We began with a methodology that was viewed negatively by many in the California agricultural community, and finished with still imperfect, but much more accepted and understood emissions estimates.

Previous estimates of agricultural emissions were typically performed by ARB based on secondary sources of information about agricultural activity in California. A major shift in developing the updated agricultural inventory was to consult with people and groups actually producing the crops in California -- the farmers and other hands-on agricultural experts. This approach lead to a series of outreach meetings with the agricultural community. We first began by presenting the current methodology and described the need for crop-specific information about California farming practices. We also stressed that the meeting participants would have an opportunity to review the agricultural activity data and any resulting agricultural emission estimates prior to releasing the new information to the public. We acknowledged the shortcomings of the agricultural tilling emission estimation method in AP-42, but argued that the emission rate of a few pounds of PM_{10} per acre was a reasonable value when compared to published field tests.

Detailed, crop-specific agricultural activity information was collected from the farmers in the form of a crop calendar. Crop calendars describe what specific agricultural operations are performed for each crop, for each month of the year. Over the course of two meetings we were able to

develop crop calendars for crops representing 90% of the acreage under cultivation in the San Joaquin Valley. By extrapolating these known crops to similar crops, we were able to update the activity data for over 95% of the crop acreage in California using new crop calendar data. Not only did this improve the annual emission estimates by refining the acre-pass counts, but it tremendously improved the seasonal resolution of the emissions inventory.

To further improve the estimates we also used GIS based soil coverages to derive county specific soil silt values for entry to the AP-42 equation. To develop these more region specific estimates, we initiated a process to estimate localized soil properties based on digitized soil texture data the ARB obtained from the Natural Resources Conservation Service (NRCS)[8]. Unfortunately, the NRCS soils data were not immediately compatible with the data needed for the windblown dust equation. To allow use of the NRCS data, ARB staff developed a conversion algorithm to convert the NRCS 'wet' percent silt value to the 'dry' silt value necessary for the soil preparation dust equation[9]. The algorithm was developed and verified using San Joaquin Valley soils analysis data collected by UC Davis[10].

In addition, we applied an estimated moisture adjustment factor to the soil preparation dust emissions during the months of December through March. This was done to try to account for the higher rainfall (and lower dust) levels during these months. December and March baseline emissions were reduced by 25%, and the January and February emissions were reduced by 50%. Although this correction is based on very limited data[11], our belief is that this correction produces seasonal emission levels which are much more realistic than the previous estimates. We also have added new emissions estimates for the harvesting of almonds, walnust, and cotton. These estimates are based on recent California emission factors developed by UC Davis[12]. We will incoporate additional havest emissions estimation as new emission factors are available.

E.   Agricultural Windblown Dust

Our inventory improvements made their largest impact on the windblown dust estimates. Our first step was to improve the climatological data that went into the soil erosion equation used to estimate windblown dust emissions. These new data include region specific temperature, rainfall, and windspeed data. The climatological data have been processed to provide both annual and monthly profiles of climate based wind erosion conditions throughout most of California. This approach gives a much better representation of the seasonality of windblown dust emissions.

The existing windblown dust equation does not explicitly account for irrigation effects, which tend to reduce emissions. To alleviate this deficiency, we developed a method to include the dust reducing effects of irrigation by treating the irrigation as a form of precipitation. The adjustment takes into account the overall soil texture, number of irrigation events, and the fraction of wet days during the time period. The existing erosion equation also does not take into account the effect of growing crop cover on windblown dust emissions. Using information gathered from agricultural experts, monthly crop canopy profiles were developed for the major California crops. Using these profiles, the erosion potential for the soil under each crop was modified based on the quantity of vegetation growing and protecting the soil from erosion. Our updated estimates also include factors for the post harvest soil cover, post harvest planting, and the amount of bare and unplanted border area for all of the major California crops.

In summary, our windblown dust estimates are now computed on a monthly basis using location specific soils, climatic, and land use data. We also incorporate crop specific irrigation, crop coverage, farming practice, and land use data into the windblown dust equation. This work could not have been done without using geographic information system (GIS) technology for emissions estimates. Overall, the methodology improvements reduced the PM_{10} windblown dust estimates by about 80%. For a more complete description of all the changes to the windblown dust estimation methodology, refer to Reference 13, which is included in these proceedings.

III. RESULTS

As Table 1 summarized, a large number of improvements were made to the PM_{10} emission inventory estimates. On a statewide basis, the emission inventory improvements reduced the emission estimates by about 50%. Table 1 shows the overall changes for each source category. Figure 2 graphically shows the changes in the statewide PM_{10} emission estimates for each of the major PM_{10} source categories[14]. Some of the largest downward corrections are in the windblown dust and paved road dust categories.

Improvements to the PM_{10} inventory also strengthened our seasonal emissions estimates. The new estimates now better track the ambient levels of measured particulate matter emissions. Figure 3 illustrates this correlation. The first two columns compare the inventoried particulate emissions with the chemical mass balance source (CMB) apportionment data in January in the San Joaquin Valley[15]. The inventoried data column has an 'INV' suffix, and the CMB data column has a 'CMB' suffix. The key point here is that in January the contribution of fugitive dust emissions, as shown by the darker blocks at the bottom of the bars, is relatively small. In November, the situation is different. CMB analysis of ambient air data indicates that there should be higher levels of geologic dust emissions. The PM_{10} inventory now reflects this, as shown by the 'NOV-INV' column which indicates a fugitive dust contribution of over 60%. Prior to our inventory improvements, each month looked similar to the annual value shown in the last column of the figure. This annual value does not accurately reflect either the seasonal variations in the quantity of the PM_{10} emissions, or the sources contributing to the emissions. The updated inventory much better represents the variations in the sources and levels of monthly PM_{10} emissions.

IV. ONGOING AND PLANNED PARTICULATE MATTER INVENTORY RESEARCH

Our efforts of improving PM_{10} emission inventories are far from complete. Many studies are still ongoing and being planned to better estimate particulate matter emissions. The ARB has ongoing contracts with UC Riverside to study the sources of paved road dust and UC Davis to develop improved activity data for unpaved road travel. Contracts are also ongoing as part of the California Regional Particulate Air Quality Study (CRPAQS) to continue measuring emissions from agricultural and livestock activities. In addition, the CRPAQS is initiating a research project to develop methods for resolving the sources of geologic PM within ambient air. This ambitious project includes the evaluation of a gamut of possible soil source identification techniques including morphology, DNA profiles, spectroscopy, organic compound fingerprinting, and others. Within the ARB, we are continuing to improve our GIS capabilities allowing us to produce more refined, location specific, estimates. We are also developing interactive GIS inventory maps which can be viewed via the Internet.

V. CONCLUSION

We have made considerable improvements to the PM_{10} inventory estimates. Our current estimates are now better accepted by affected agencies and industry. Also, more justifiable and cost effective PM_{10} control plans can now be developed to protect the health of Californians.

With the PM_{10} SIPs submitted, the intensity of effort expended these past years to improve the PM_{10} inventory probably marks a high point in our near-term PM_{10} inventory efforts. Now, while we still focus on PM_{10} emissions estimates, we also begin to turn our attention to the $PM_{2.5}$ inventory, which is virtually non-existent. Through our PM_{10} inventory improvements, we have put into place a new, cooperative approach to inventory development. This approach and the positive working relationships we have developed with researchers and industry will help us to continue improving the PM_{10} inventory, while pressing ahead in preparing $PM_{2.5}$ inventories in support of the new $PM_{2.5}$ Federal attainment plans.

DISCLAIMER
The opinions, findings, and conclusions expressed in this paper are those of the staff and not necessarily those of the California Air Resources Board.

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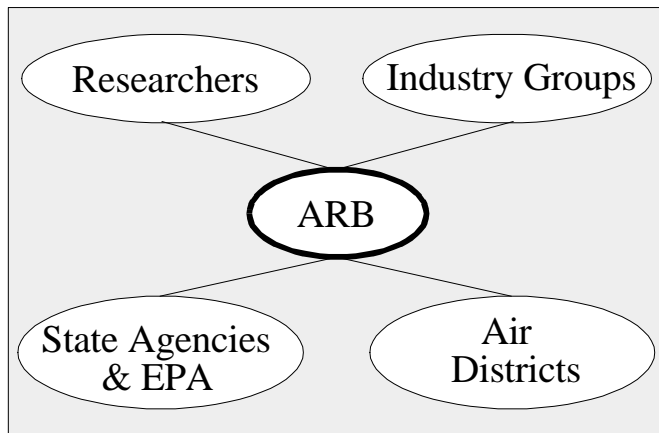
Figure 1. ARB's PM_{10} Inventory Outreach.

Table 1. Contributors to California's PM_{10} Inventory Improvements.

Organization	Contribution to Inventory Improvement
Air Quality Agencies - California Air Pollution Control Districts - Nevada and Arizona air quality agencies	 Technical and policy assistance and coordination for regional issues, technical review Partners in emission factor development for paved roads and construction (under BACM group), technical review
State of California - California Department of Water Resources (DWR) - California Department of Food and Agriculture (CDFA) - California Department of Pesticide Regulation (DPR) - California Department of Transportation (Caltrans)	 GIS land use data Crop acreage data GIS land use data Paved roadway categorization, unpaved road mileage
Federal Agencies - Natural Resources Conservation Service (NRCS) - USDA-Agricultural Research Service - US EPA	 GIS soil texture data, technical expertise in interpreting soils data Assistance with improvements to ARB's windblown dust methodology Funding for BACM group studies
Researchers - University of California, Davis - University of California, Riverside, CE-CERT - Desert Research Institute - UC Cooperative Farm Extension representatives	 Soil analysis data, agricultural soil preparation and harvest emission factors, ammonia research, paved road dust research Paved road dust research Unpaved road dust emission factors, particulate matter size speciation data Agricultural crop calendar and activity data, agricultural process expertise
Industry - California Cotton Ginners & Growers Associations - Nisei Farmers League - San Joaquin Valley commodity producers	 Agricultural crop calendar and activity data, agricultural process expertise, research funding assistance
Other Agencies - PM_{10} Best Available Control Measures Working Group (BACM) - California Regional Particulate Air Quality Study (CRPAQS) - Local Councils of Governments and transportation agencies - San Joaquin Valley Agricultural Commissioners	 Paved road emission factors, construction emission factors, uninventoried sources emission estimates Emissions research, PM_{10} analysis, coordination and funding field studies Vehicle traffic estimates Agricultural process expertise

Table 2. Changes to the PM_{10} Fugitive Dust Inventory.

Emissions Category	Inventory Improvement[*]					PM_{10} Emissions (1993, tons/year)		
	EF	AD	TD	SD	Method	Before	After	% Change
Paved Road Dust	X	X			X	1563	390	-75%
Unpaved Road Dust	X	X	X			937	570	-39%
Construction Operations	X					510	170	-67%
Agricultural Land Preparation & Harvest	X	X	X	X	X	360	220	-39%
Agricultural Windblown Dust	X	X	X	X	X	1500	320	-79%

[*]Codes Used for Inventory Improvement
    EF   - Emission Factor
    AD - Activity Data
    TD - Temporal Data
    SD - Spatial Data
    Method - Substantial changes in overall method

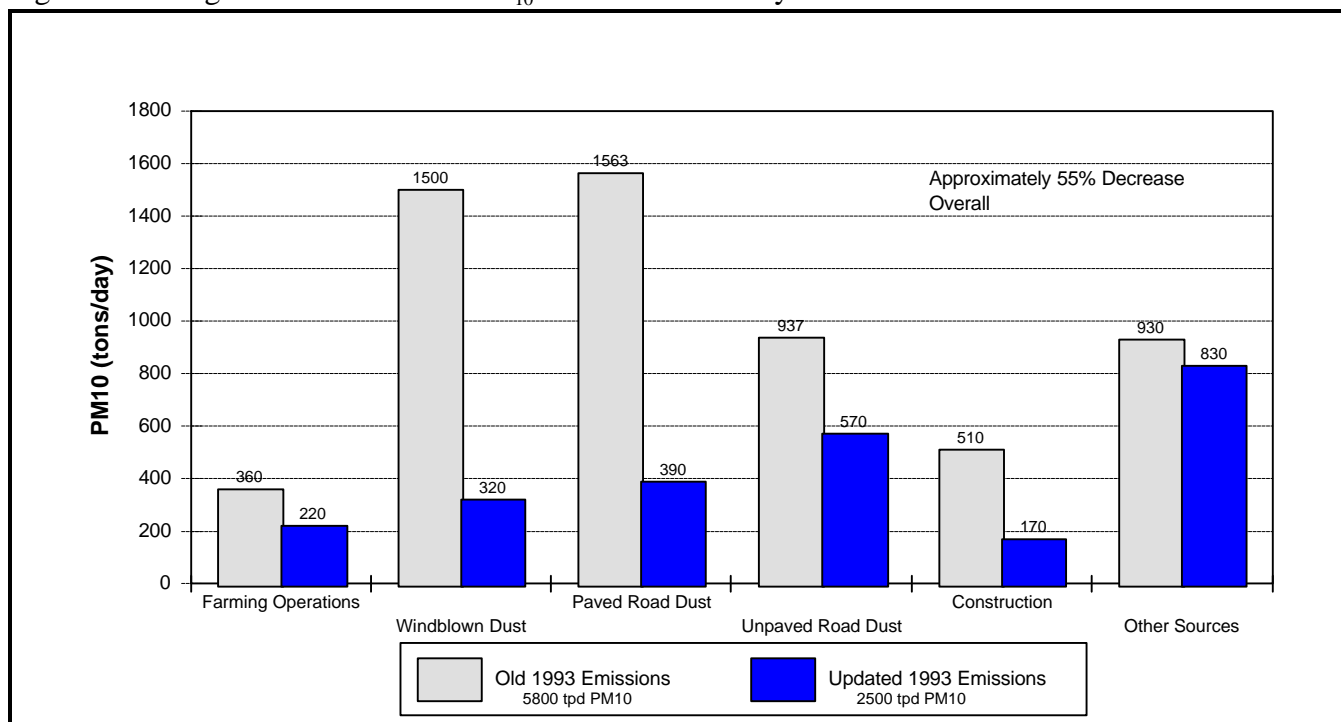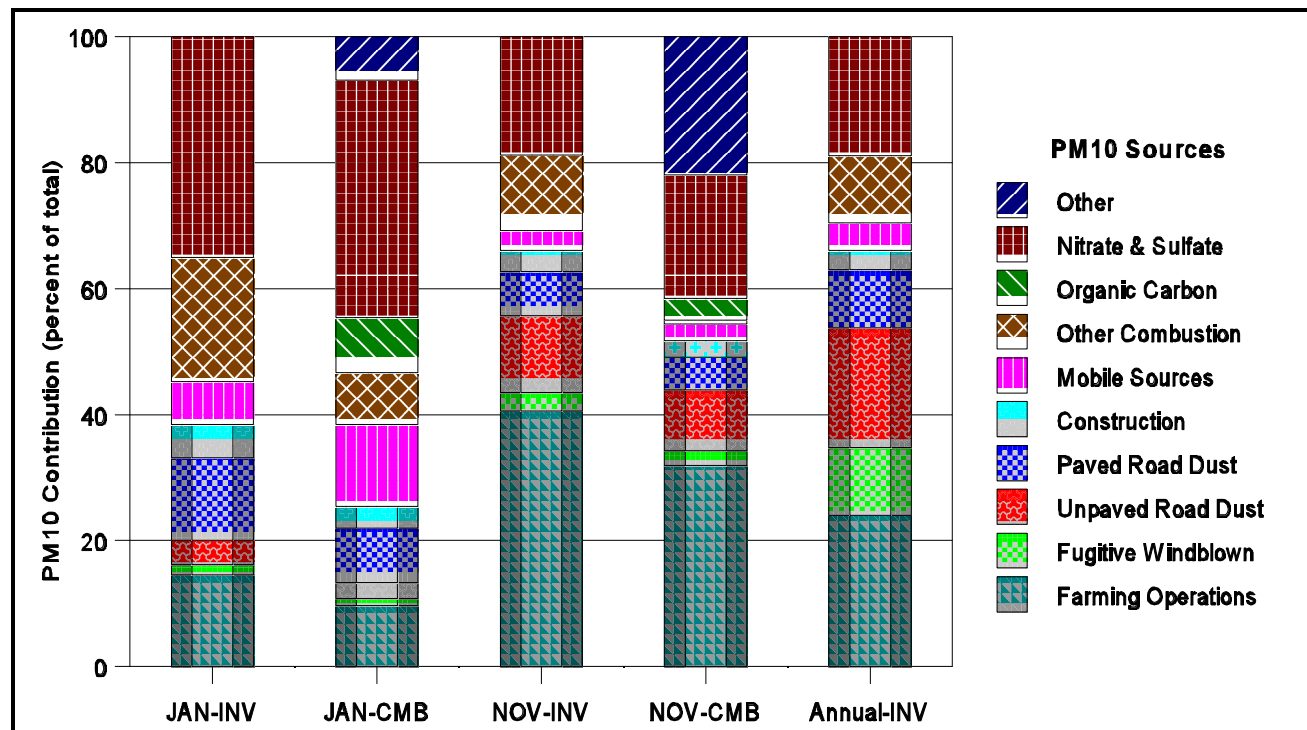Figure 2. Changes in the California PM_{10} Emission Inventory for 1993.

Figure 3. Contributors to PM$_{10}$ Emissions, San Joaquin Valley
Inventoried versus Ambient Chemical Mass Balance Sources.

Description: This chart compares the contributions of fugitive dust emission sources from the inventoried (INV) and chemical mass balance (CMB) particulate matter source estimates in the San Joaquin Valley. The dark, lower portion of the bar shows the fugitive dust sources; these include construction, paved and unpaved road dust, windblown dust, and farming operations. Source profiles are shown for January and November. The bars show that in January, both the inventoried and CMB data show fairly small fugitive dust contributions. In November, the fugitive dust contributions are larger for both the inventoried and the CMB data.

Notes for Table 3

JAN-INV: ARB 1993 January PM$_{10}$ inventory[11], San Joaquin Valley. Added estimated secondary emissions of 36% based on CMB analysis.

JAN-CMB: CMB analysis, Fresno, CA[12]. January 20, 1994. Fugitive dust emissions apportioned based on January inventory values.

NOV-INV: ARB 1993 November PM$_{10}$ inventory[11], San Joaquin Valley. Added estimated secondary emissions of 19% based on CMB analysis.

NOV-CMB: CMB analysis, Corcoran, CA[12]. November 9, 1993. Fugitive dust emissions apportioned based on November inventory values.

Annual-INV: ARB 1993 annual PM$_{10}$ inventory[11], San Joaquin Valley. Added estimated secondary emissions of 18% based on average annual CMB analysis for Bakersfield, Fresno, and Visalia.

KEY WORDS

PM_{10} Emissions Inventory
California PM_{10}
Sources of PM_{10}
Improving PM_{10} Emission Inventories
PM_{10} Studies in California